

THIS article tells how crop rotation is related to soil fertility, to the control of plant diseases and weeds, and to erosion control. It gives examples of good rotations and discusses the factors that are important in planning rotations for a particular farm. Finally, it outlines the rotation systems adapted to the major farming regions of the United States, shows what the actual practices are, and suggests possibilities for modifications.

Crop Rotation

By CLYDE E. LEIGHTY¹

IN CONTRAST to the continuous growing of a single crop on the same land, or to haphazard cropping of the land without plan or studied design, the systematic rotation² of crops may have many advantages. First and foremost, perhaps, is the provision made in a good rotation for maintaining or improving the fertility of the soil. Usually this requires the growing of a legume and sod crop to promote fixation of nitrogen and maintenance of humus. As manure is exceedingly useful in maintaining fertility, abundant roughage and pasture for animals is provided by crops in the rotation. If no animals are kept on the farm, green manures and crop residues may be plowed under in place of yard and stall manures to maintain the supply of organic matter.

FACTORS CONTROLLING ROTATIONS

The determination of the crop rotation to be used on a farm involves consideration of many and diverse factors. Basic to the choice of a rotation is the farmer's desire to get the most out of his farm for the effort he puts into it. The fertility of the soil, its tilth, drainage, reaction, and slope, the temperature, rainfall, weeds, plant diseases,

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² "Crop rotation" may be defined as the growing of different crops in recurring succession on the same land, in distinction from a one-crop system or a haphazard change of crops determined by opportunism or lacking a definite plan. Many definitions of crop rotation given in textbooks, bulletins, dictionaries, and encyclopedias go beyond their field and tend to limit the term by defining good rotations or by bringing into the definition the attributes or purposes of a good rotation or the objects sought to be accomplished by it. Obviously a crop rotation may be good or bad in its effects on the soil and in its economic returns. In rotations, the change in crop may be annual; after several years, as with alfalfa; or after many years, as with orchards; but with most crops and soils rotation is desirable.

and insect pests determine certain limitations to the kinds and proportions of crops to be grown. Within these limits the relative prices of the products that can be produced, the labor distribution through the season, and the prices of materials and labor used in production determine more definitely the acreages devoted to the various crops and the number of each class of livestock. Personal preferences for certain crops and kinds of livestock may be important for a few years but become less so as the pressure of these other factors is increasingly felt.

Adaptation to soil types is generally recognized as an important factor in determining what crops should be grown. Very often there is considerable range in adaptation of a crop, but definite limitation for one reason or another with respect to certain soil types.

What crops should be grown and their sequence in the rotation is frequently dependent on topography. Rotations suited to level land may be entirely unsuited to steep slopes on the same farm. By use of proper rotations the liability of serious erosion may be materially decreased.

In its essentials a good crop rotation utilizes crops that are adapted to the environment and that fit into a farming system that is planned and integrated as an efficient business undertaking. Methods should be employed that will maintain or improve yields, and to this end attention must be given to (1) maintenance of soil fertility, (2) plant-disease and insect-pest control, and (3) weed control.

Diversification and Crop Conflicts

It generally pays a farmer better to have several important products rather than only one. Diversification provides against total failure, distributes the income over the year, and tends to provide year-around work for men, machinery, and horses. Diversification is accomplished best through crop rotation, as by this means maintenance of yields tends to be assured. With only one product the risk of failure due to weather, pests, and prices is much greater than with several crops, all of which are not likely to suffer from the hazards occurring in any particular year.

Seasonal distribution of labor is of first importance in determining crops that may be grown and therefore in determining what rotation may be followed. A full year's work for men and teams is generally essential for farm success. Conflicts in labor requirements of crops are frequent. Alfalfa, corn, and winter wheat seriously conflict in Kansas and Nebraska. All are good crops. When wheat is most profitable, it is grown at the expense of the other two with resulting limitation in livestock. In the Corn Belt, corn pays better than alfalfa and so is more generally grown. Corn combines well in the Corn Belt with clover and timothy hay and with oats, but not with sugar beets. When there is serious conflict between crops, the more profitable one is likely to be grown. When there is little difference in profit, two or more crops may be grown on the same farm, despite their conflict, especially when much the same equipment may be used for both.

Farm Lay-Outs

In establishing a rotation on a farm, attention to farm lay-out is of much practical importance. Fields and pastures should be so arranged that farm operations may be conducted most efficiently. Many different factors will require consideration in establishing a satisfactory lay-out. These will vary from farm to farm according to topography; permanent features, such as roads, streams, and ditches; soil variations; type of farming, crops to be grown, and live-stock to be kept; size of farm; machinery to be used; location of buildings; and other conditions that will suggest themselves as the problem is studied.

The simplest and most economical lay-out is one of square fields of uniform soil and nearly equal size. In many areas, however, rough land, woodland, or other natural features may seriously interfere with such an arrangement; and the necessity of protecting the soil against erosion may make it entirely inadvisable.

Planning Rotations

Rotation of crops is necessarily based on a long-time plan. The plan itself to be sound must have back of it a fund of accumulated knowledge. This may have been accumulated by the farmer himself or by his neighbors, or it may be based on experiments conducted by experiment stations. It presupposes certain decisions by the farmer.

Within certain limits a rotation need not be inflexible. It may be varied in details from year to year as information accumulates or as conditions change. These modifications often may be made without disturbing the essential plan of the rotation, as in substituting barley for oats as a spring-sown small-grain crop. The principles of a sound rotation, however, should be followed whenever a change is made. "To simplify the planning of rotations, field crops are divided into three classes, grain crops, grass crops, and cultivated crops" (154).³ Bare summer fallow, as practiced under semiarid conditions, may be regarded as a cultivated crop. Bearing in mind this classification, considerable elasticity may be allowed in carrying out a definite or fixed rotation without interfering with its purposes.

It may sometimes be desirable to make a radical change in a rotation, involving change even in the type of farming being practiced. As a rule such radical changes are made reluctantly by farmers, who are apt to proceed too slowly rather than too suddenly or too fast. The improvement in agriculture that followed the eventual adoption of the enclosure system in France, as also in England, was marked. Crop yields were increased manyfold as a result of the gradual increase in soil fertility that came about through the better methods, which farmers in the beginning bitterly opposed.

The demand of consumers for farm products on the one hand and the supply of the various products that farmers can produce profitably at prevailing prices on the other have resulted in a variety of crop rotations for different parts of the country. In some areas crop rotations have changed little in recent years. In other areas changes

³Italic numbers in parentheses refer to Literature Cited, p. 1181. Other publications dealing with the subjects in this article but not specifically referred to are: (10, 24, 34, 43, 50, 119, 151, 189, 194, 205, 206, 207, 208, 225, 262, 264, 272, 286, 288, 330, 348, 357, 358, 372, 396, 408, 441, 456, 476).

are still taking place. During the past 10 years, for example, the proportion of potatoes to other crops has increased greatly on many farms in central New Jersey, owing to improvements in tractors, potato machinery, improved seed, spraying, and fertilizer practices. Similar conditions have stimulated an increase in the proportion of potatoes grown on farms in Aroostook County, Maine. Wheat production in the Great Plains States was greatly stimulated by improvements in tractors, combines, and certain tillage machinery.

Example of a Good Rotation

Some of the essentials of a good rotation are illustrated by one practiced by many farmers in the Northeastern States. This is a 5-year rotation of corn, oats, wheat, and 2 years of clover and grasses.

Farmers practicing this rotation usually feed the corn and oats and most of the hay to cattle and sell dairy products, wheat, and some hay and livestock. The growing of wheat and hay as cash crops distributes the risk much better than if dairy products were the only source of income. Pasture for livestock may be provided by the clover and grasses, but permanent pasture is often available on land unsuitable for cultivation. It may be necessary to buy some feed and grain concentrates.

The cultivated crop, corn, controls weeds and uses manure effectively; it provides both grain and stover for feed, or the entire crop may be used for silage. The 2 years of clover and grass in the rotation provide hay and pasture, and are of benefit to the soil through the addition of nitrogen and organic matter. Wheat is a good nurse crop for the clover and grass.

Manure produced by the livestock, when handled properly, helps to maintain fertility and to reduce expenditures for commercial fertilizers, as does the use of legumes in the rotation. Manure is usually applied preceding corn, but some of it may be used on the meadows. Fertilizers may be used with oats, wheat, and grass.

Oats may often be sown on disked cornland. With disking of the cornland, plowing is necessary only twice in 5 years, in preparation for corn and wheat. In more southern areas, however, it is desirable to grow a cover crop on the land during the winter to prevent leaching of soluble plant foods. This necessitates one more plowing, but benefits from the crop overbalance this cost.

RELATION OF CROP ROTATION TO SOIL FERTILITY

Various factors are concerned in the maintenance of soil fertility. These include drainage, irrigation, organic matter, crop residues, farm manures, cover crops, soil reaction, liming, fertilizers, tillage, and crop rotation. Generally speaking, less thought is given to the benefits accruing from crop rotation than to those from some of the other factors. This is probably owing to the fact that farmers practicing crop rotation have no direct means of visualizing its beneficial influences, whereas the use of manure, lime, or fertilizer is as a rule reflected in an appreciable increase in crop growth and production. The increased yields resulting from the practice of systematic crop rotations is well illustrated by the experimental work of a number of the State agricultural experiment stations (fig. 1).

Among the outstanding advantages of crop rotation from a soil-fertility standpoint are: (1) It keeps soil in suitable physical condition; (2) it helps to maintain the supply of organic matter and nitrogen in the soil; (3) it provides a practical means of utilizing farm manure and fertilizer; (4) it keeps the soil occupied with crops; (5) it changes the location of the feeding range of roots; (6) it counteracts the possible development of toxic substances; and (7) it improves crop quality.

The rapid loss of the soil organic matter resulting from growing the same crop continuously has a distinctly bad effect on good tilth. Loss of organic matter from sandy soils has a tendency to make them looser and subject to leaching; and the clays, clay loams, and loams lose their crumb structure, becoming much less easily plowed and cultivated and more easily puddled into hard lumps if plowed or otherwise worked when too wet. The importance of preventing such a soil condition cannot be overemphasized. The growing in rotation of suitable crops—grass, pasture, and deep-rooted legumes—on soils inclined to puddle is essential to maintain the soil organic matter and with it proper tilth. A rotation that includes a sod crop helps to maintain the organic matter supply of the soil and furnishes raw food material for soil bacteria.

By alternating shallow-rooting with deep-rooting crops, different soil horizons serve as feeding ranges, which has a tendency to prevent the exhaustion of available plant food in localized areas. Deep-rooted plants, such as clover and alfalfa, alternating with shallow-

SOUND ROTATIONS INCREASE FARM EFFICIENCY

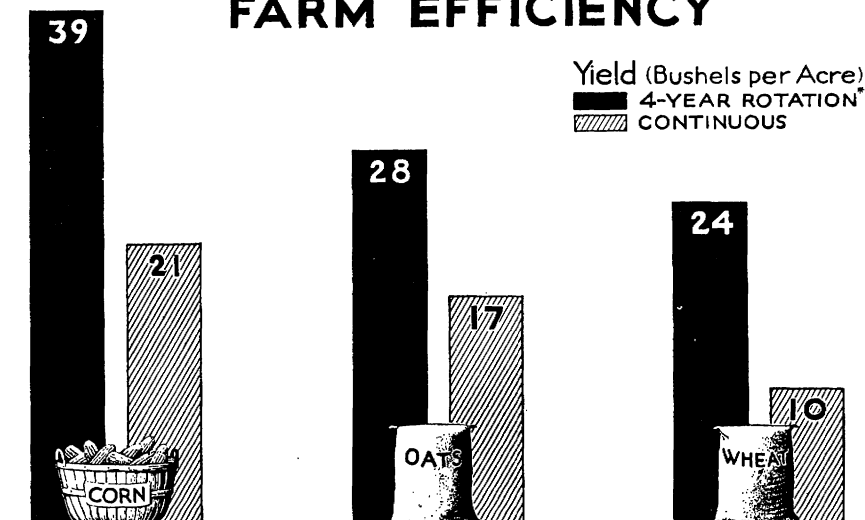


FIGURE 1.—Average yields of corn, oats, and wheat in a 4-year rotation and continuously cropped at the Missouri Agricultural Experiment Station.

rooted crops, improve the physical condition of the soil and subsoil. Deep root penetration on the part of certain leguminous crops not only provides better drainage, resulting from channels left after the roots decay, but effects a withdrawal of plant-foot elements from lower depths and leaves root residues to help maintain the organic matter and plant-food content of the soil.

Well-arranged systems of crop rotation make practicable the application of manure to the most responsive crops or to those crops that have a long growing season or a high money value. The use of manure is also indicated on crops that are rated as gross feeders, such as corn. Where manure is lacking, the same practice applies to the use of commercial fertilizer. Fertilizers are best applied to the cash crops. For example, in a rotation of corn, oats, wheat, and mixed hay (clover and timothy), the corn and wheat are fertilized, the oats and hay having to depend on any residual fertilizer. In such a rotation, manure, if available, would be applied to the cornland.

Crop rotation, in contrast with continuous cropping, makes it possible to have the land occupied with a suitable crop most of the year. The loss of plant food by leaching is minimized, and losses from soil erosion are greatly reduced as compared with unoccupied land.

The growing of one crop year after year may lead to the development of certain organic toxic compounds resulting from improper decomposition of soil organic matter. Crop rotation insures normal decomposition processes and thereby affords a practical means of preventing the formation and accumulation of injurious substances in the soil.

Crop rotation not only tends to favor higher crop production, but as a rule insures better crop quality than continuous cropping. There are numerous cases on record to show the advantageous effects of rotating crops on yield and quality. The fact that the ravages of insect pests and of plant diseases are reduced to a minimum in a crop-rotation system as compared with continuous cropping is an insurance for better crop quality. In many instances the chief emphasis so far as quality is concerned has been placed upon the cereal crops. Quality factors in these crops involve chiefly test weight per bushel, plumpness of kernel, and protein content of the grain, all of which are generally improved as the result of rotation. The beneficial influences of crop rotation and any soil treatment supplementing it are important factors in hastening the maturity of crops. This is particularly true of corn, which is susceptible to early frosts.

In considering the advantages of a systematic crop rotation, it is evident that when compared with continuous cropping a rotation system helps to maintain soil fertility and frequently increases it, but it should not be depended upon entirely to do so. Rotation of crops is one thing. The use of manure and fertilizer is another. By combining the two intelligently, best results have been obtained and soil fertility more adequately maintained at a high level. The rational use of manures and commercial fertilizer in conjunction with crop rotation will prevent soil depletion much more effectively than rotation alone. This is well borne out by the long-time rotation studies of the Illinois Station, as reported by DeTurk, Bauer, and Smith (91).

WHICH ROAD SHALL WE FOLLOW?

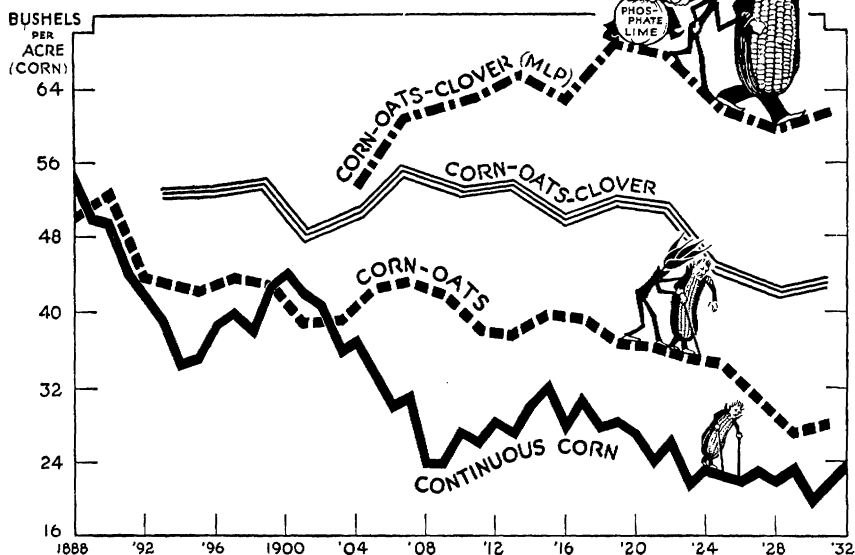


FIGURE 2.—Yields of corn grown continuously; corn grown in a 2-year rotation of corn and oats; and corn grown in a 3-year rotation of corn, oats, and clover, with and without fertilizer, on the Morrow field plots of the University of Illinois.

The practical results of these studies are illustrated in figure 2.

Not only is it true that crop rotation plus proper fertilizer treatment tends to maintain the organic matter and nitrogen content of the soil; it also tends to maintain the activities of soil bacteria at a high degree of efficiency, which in turn is reflected in an increased supply of available nitrogen, as nitrates, and a better opportunity for the mineral plant-food constituents to be rendered available to plants.

LEGUMES IN ROTATIONS

The growing of legumes in the cropping system is widely recognized as useful in the maintenance of fertility. But some legumes, like soybeans and cowpeas when harvested for hay, may be grown in regular order in a rotation with little or no benefit to the land through addition of nitrogen, which is the only element added by legumes. Other elements such as potassium and calcium may be decreased even more rapidly by some legumes than by some nonleguminous crops.

Experiments in Kentucky (310) showed that clover was greatly superior to soybeans in the maintenance of nitrogen, when both crops were harvested for hay. Soybeans drilled solid were more effective in nitrogen conservation than when drilled in rows and cultivated. Clover also had greater residual effect than soybeans. Hay yields

were about one and a half times as large from soybeans, however, as those from clover in comparable tests. Clover would probably have less advantage, then, if all manure from feeding the hay were saved and returned to the land.

A comparison of the yields of wheat and corn following legumes turned under, legumes harvested for hay, and nonleguminous crops is shown in figure 3, which was drawn from data presented in Virginia Agricultural Experiment Station Technical Bulletin 19 (165). In this case the inclusion of a legume increased the yield above that of rotations not containing a legume, even when the nonleguminous crop (rye) was turned under. Turning under the legume still further increased the yield.

A 1-year cropping system has been devised and used successfully for several years in Missouri in which Korean lespedeza is grown following a small-grain crop each year. Wheat, oats, barley, and rye used in this way may be harvested for grain or used for hay or pasture. The lespedeza following the grain crop may be used during the summer for hay, seed, or pasture. The land may bedisked in preparation for grain seeding. Where seeding may be delayed in the fall until the lespedeza seed is mature it will reseed itself year after year; otherwise sowing of the grains in the early spring will be necessary.

This system has several advantages. As a legume is grown every year, it is useful in improving poor land. The land is protected from erosion by a growing crop the entire year, except for a few weeks after seeding the grain crop. The system thus may be used to advantage on rather steep land. It may be used on single fields where a

WHEAT AND CORN YIELDS IMPROVE AFTER LEGUMES

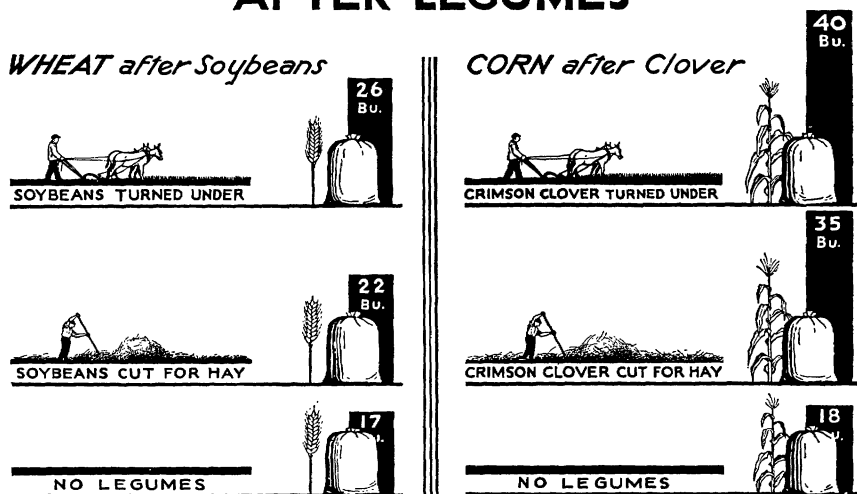


FIGURE 3.—The 7-year average yields of wheat and corn following legumes turned under, legumes harvested for hay, and nonleguminous crops at the Virginia Agricultural Experiment Station.

longer rotation might not be applicable, and it may be readily shifted from field to field. Both the grain and the lespedeza may be utilized in any one of three ways—harvested for grain or seed, pastured, or cut for hay.

It is well understood that legumes to be effective as nitrogen gatherers must be inoculated with their proper organisms. A further characteristic of legumes is that even though they are properly inoculated they fix nitrogen from the air only to the extent that the supply in the soil is insufficient for their needs. In a soil where the nitrogen content is low, then, the legumes are more effective in gathering nitrogen. This would indicate that the legume crop in the rotation should not follow the crop to which manure is applied, because not all of the manure is likely to be used by this crop and its remnants will tend to reduce the activity of nitrogen-fixing organisms. If two or more crops intervene after application of manure and before the legume is grown, the latter will be more effective as a nitrogen gatherer.

In consideration of legumes in rotations, not only fixation of nitrogen but also its utilization and its conservation are of importance. Even when considerable nitrogen is gathered by the legume, much of it may be lost from the soil in common farm practice, and therefore full benefit from growing the legumes often is not realized. These losses may come about through nitrogen being leached into the subsoil out of the reach of plant roots or being carried away in run-off water. In order to avoid these losses the crop rotation and the practices in growing crops must be designed with this purpose in mind.

The annual legumes, whether harvested or not, should be followed by fall-sown grain—wheat or rye in northern areas, or wheat, rye, barley, or oats farther south. These crops will take up much of the soluble nitrogen and prevent its loss by leaching. Unless these grains are sown quite early, they will not make sufficient growth in the fall to utilize all the nitrogen. But such plantings are always advisable either for grain production or as catch crops for plowing under the following spring in preparation for other crops, for in addition to nitrogen conservation the grains serve a useful purpose in minimizing soil erosion during the winter.

CROP ROTATION IN RELATION TO THE CONTROL OF PLANT DISEASES

Crop rotation has been advised for the control of many plant diseases. In some instances the most effective known control measure is rotation combined with seed treatment and general sanitary measures, but these methods are of little or no avail in the case of many diseases.

Certain parasites remain from season to season in the soil, living on plant refuse from the previous crops or coming from other sources, and when susceptible crops are grown every year the parasites tend to accumulate to a point which makes production unprofitable. It is for this group of parasites that crop rotation has made the best showing as a control measure. However, it should be emphasized that in most cases the efficiency of rotation as a control measure depends on using clean seed, seedlings, or bulbs, and following field-sanitation measures. In table 1 will be found the outstanding examples of diseases that can be so controlled and condensed notes on procedures.

Table 1.—*Plant diseases that are controlled entirely or in part by means of crop rotation, with notes on procedures*

Disease	Chief crop plants affected	Causal organism	Years crop is on and off land		Resistant or immune crops which may be used	Remarks
			On	Off		
Scab of cereals.....	Wheat, barley, rye, corn.	<i>Gibberella saubinetii</i> (Mont.) Sacc.	Number 1	Number 1-2	Oats, soybeans, clover, alfalfa, flax.	In badly infested areas wheat, barley, rye, and corn should not be grown in any sequence within the group. Crop refuse should be burned or plowed deeply. Use clean seed. Use resistant varieties where available.
Flag smut.....	Wheat.....	<i>Urocystis tritici</i> Koern.....	1	1	Any crop except susceptible wheat.	Resistant varieties of wheat available.
Diplodia disease.....	Corn.....	<i>Diplodia zeae</i> (Schw.) Lev.....	1	1-2	Any crop except susceptible corn.	Crop refuse should be burned or plowed deeply. Use clean seed. Resistant varieties of corn available.
Nematode disease.....	Wheat, rye.....	<i>Anguina tritici</i> (Steinbuch) Filipjev.	1	1	Any crop except rye, wheat, and species closely related to wheat.	Use clean seed.
Wilt.....	Alfalfa.....	<i>Phytophthora insidiosa</i> (L. McC.) Bergey et al.	3-4		Any crop including alfalfa.....	Alfalfa can follow alfalfa. The point is to maintain short stands.
Stem nematode.....	Alfalfa, red clover.....	<i>Ditylenchus dipsaci</i> (Kuhn) Filipjev specialized strains.		2	Any cultivated crop.....	
Black rot.....	Sweetpotatoes.....	<i>Ceratostomella fimbriata</i> (Ell. and Halls.)	1	3-4	Any crop other than sweet-potatoes.	Seed and seedbed must be free of parasite.
Foot rot.....	do.....	<i>Phenodonus destruens</i> Hart.....	1	2-4	do.....	Do.
Scurf.....	do.....	<i>Monticolaetes infuscans</i> Halls.....	1	3-4	do.....	Do.
Anthracnose.....	Beans.....	<i>Colletotrichum lindemuthianum</i> (S. and M.) Bri. and Cav.	1	2	Any crop other than beans.....	Use clean seed.
Blight.....	do.....	<i>Bacterium phaseoli</i> E. F. S.; <i>Bacterium medicaginis</i> var. <i>phaseolicola</i> (Burk) Link & Hall.	1	2	do.....	Do.
Wilts.....	Potato, tomato, egg plant.	<i>Verticillium</i> spp. and <i>Fusarium</i> spp.	1	3-5	Small grains, grass, corn, and legumes.	Especially recommended in Oregon. Use resistant tomato seed.
Bacterial canker.....	Tomato.....	<i>Aplanobacter michiganense</i> E. F. S.	1	2	Any crop other than tomato.....	For Utah. Use clean seed.
Anthracnose.....	Cucumber.....	<i>Colletotrichum lagenarium</i> (Pass.) E. and H.	1	2	Any crop other than cucumber, muskmelon, watermelon, and gourd.	Use clean seed.
Bulb rot.....	Onion.....	<i>Fusarium</i> spp.....			Any crop other than onion.....	Use bulbs free from parasite.

Table 1.—*Plant diseases that are controlled entirely or in part by means of crop rotation, with notes on procedures—Con.*

Disease	Chief crop plants affected	Causal organism	Years crop is on and off land		Resistant or immune crops which may be used	Remarks
			On	Off		
Texas root rot.....	Cotton.....	<i>Phymatotrichum omnivorum</i> (Shear) Duggar.	Number 2-3	Number 3-4	Grain sorghum, corn, small grains, and grasses.	Refuse plowed under deeply.
Nematode root knot.....	do.....	<i>Heterodera marioni</i> (Cornu) Goodey.	2-3	3	Alfalfa.....	Upland cotton in irrigated district of California.
Black shank.....	Tobacco.....	<i>Phytophthora parasitica</i> var. <i>nicotianae</i> .	1	4	Sorghum, small grains, and alfalfa.	Pima cotton in irrigated district of Arizona.
Black root rot.....	do.....	<i>Thelariopsis basicola</i> Zopf.....	1-2	5-6	Any common crop other than tobacco.	Method recommended for western North Carolina, but not for Florida. Seedbed must be free of parasite.
Granville wilt.....	do.....	<i>Bacterium solanacearum</i> E. F. S.	1	3-4	Grass crop and weeds.....	Resistant varieties of tobacco are available. Seedbeds must be free of parasite.
Nematode root knot.....	do.....	<i>Heterodera marioni</i> (Cornu) Goodey.	1	2-3	Corn, small grains, forage grasses, cotton, and sweet-potatoes.	Seedbeds must be free of parasite. Many weeds harbor the parasite.
Sugar-beet nematode.	Sugar beets.....	<i>Heterodera schachtii</i> Schmidt.....	1	5-6	Peanuts, velvetbeans, Crotalaria, native weeds, cereals, and forage grasses.	Seedbeds must be free of nematodes. This parasite attacks over 500 plant species.
Damping off "black root."	do.....	<i>Pythium</i> spp. <i>Rhizoctonia</i> spp	1	4-5	Alfalfa, sweetclover, beans, peas, potatoes, cereals, and vegetable crops.	Avoid all types of beets and crucifers such as cabbage, turnips, cauliflower, rape, etc. Many weeds are hosts for this nematode. Small grains should be confined to long rotations and not immediately precede sugar beets. The length of the rotation depends on the severity of the infestation.
Leaf spot.....	do.....	<i>Cercospora beticola</i> Sacc.....	1	4-5	Corn, potatoes, and other cultivated crops.	Sugar-beet stands are poorer when this crop immediately follows clover, alfalfa, or sweetclover.
					do.....	Fungus remains alive in refuse from preceding crop for at least 3 years.

The brown root rot of tobacco in northern areas, the cause of which is uncertain, is unique in that it is controlled most effectively in the field with continuous tobacco culture. Corn and other grasses in the rotation have increased the difficulties with this disease. A seedling damping-off disease of alfalfa caused by *Pythium* spp. increases in soil which is in fallow. When the infestation is not too bad the alfalfa is seeded very thickly.

Some soil-inhabiting parasites are exceedingly refractory to rotation and sanitary measures, as for example the vascular fungi (*Fusarium* spp.) which attack sweetpotatoes, peas, and beans; the white rot organism (*Sclerotium cepivorum* Berk.) of onion; the club root organism (*Plasmodiophara brassicae* Wor.) of cabbage and related plants; the flax wilt parasite (*Fusarium lini* Bolley); and the root and stem parasite (*Sclerotium rolfii* Sacc.), which attacks a wide range of plants in the Southern States.

Rotation is of no avail in the control of such diseases as the cereal rusts, mildews, most of the cereal smuts, and potato late blight. In all of these the spores of the parasites are readily carried by the wind from infested to noninfested fields.

CROP ROTATION AND WEED CONTROL

Rotation of crops, when accompanied by care in the use of pure seed, is the most effective means yet devised for keeping land free of weeds. No other method of weed control, mechanical, chemical, or biological, is so economical or so easily practiced as a well-arranged sequence of tillage and cropping. Not all weeds can be controlled by crop rotation, nor are all one-crop farms weedy. Nevertheless, weed problems are likely to be least severe on farms where crop diversification is practiced and most severe on farms devoted for one reason or another to a single crop.

Of about 1,200 species of plants commonly called weeds in the United States, less than 30 are sufficiently aggressive to be able to survive indefinitely on crop-rotated land. These are the superweeds, the so-called noxious species, plants having such extreme tenacity of life that no ordinary good farming measures control them. They include such notorious pests as Canada thistle, quackgrass, bindweed or wild morning-glory, Johnson grass, hoary cress, nutgrass, leafy spurge, and wild onion. All of these are perennials, with spreading or creeping root systems or with underground parts, such as bulbs, uninjured by tillage. A few annuals, notably wild oats and crabgrass, are so resistant to extermination that they may be classed as noxious.

Weeds, aside from the noxious species, are not a serious problem on a well-organized diversified farm. Indeed, there is little excuse for such a farm to be weedy. Most weeds are annual plants, unable to sprout from their roots, and depend upon their seeds for reproduction. Cutting them off close to the ground before the seeds ripen destroys them. In a rotation of cultivated crop, grain crop, and meadow several opportunities occur to do this. At worst the rotation can usually be shifted slightly to throw it out of balance with the weed and cause a tillage or a mowing operation to come at a time when it will do the weed the most harm. These are facts well known to all careful farmers.

A fact not usually so well understood is that weeds may sometimes be more valuable than harmful. Too clean tillage is often the cause of destructive soil erosion, and much good soil has been washed into the rivers because of a mistaken insistence on destroying every weed. Leaving a soil cover of not-too-large weeds may well be an excellent practice on rolling land. In any case, weeds have some value as organic material to be plowed under. A balance between too many weeds and too few weeds is probably a good objective if it can be arranged.

Among the common crops, alfalfa is the one best suited to compete with noxious weeds. The frequent cutting and heavy growth of alfalfa prevent weeds from going to seed and reduce their vegetative vigor. The weeds may not be killed by the alfalfa, but they are usually subdued sufficiently so that other crops can be grown for several years without too much interference. On severely infested land the weeds should be weakened by a month or two of fallow before alfalfa is planted.

The list of other good competitive crops is limited. Winter rye and winter wheat are often recommended for bindweed land because they provide intervals in midsummer for fallowing and make their own growth during the season when the weed is inactive. Sorghum, soybeans, and Sudan grass have been successful on infested land, although pretillage, especially in the drier areas, is often required for best results and pays well in increased yield of the crops.

Contrary to a widely held belief, fallowing for weed control need not be so frequent that all top growth is prevented. Permitting the weeds to make a few inches of growth between cultivations appears to weaken rather than strengthen them. Thus, cultivating every 2 weeks is as effective in killing bindweed as cultivating once a week. A combination of this kind of tillage with crops like alfalfa and winter wheat appears to be the most economical and effective rotation yet known for reducing serious infestations of the more persistent weeds.

On a large scale, weeds tend to become a very serious matter in grain-growing regions of the West. In most spring wheat areas there is little choice of crop, and the only recourse is to alternate grain growing with summer fallow. Even this does not control such hardy species as Russian-thistle. Although weed control is not the primary purpose of summer fallow, it may often be an important consideration.

In some kinds of one-crop farming, weeds, while plentiful, do not prevent the production of good yields. A notable example is the southeastern Cotton Belt, where cotton is traditionally the principal if not the only crop grown. Left to themselves the cottonfields would consist almost wholly of masses of crabgrass by the middle of summer. The only thing that makes cotton growing possible is the fact that the cotton is chopped, or hoed, often several times during the season. The first chopping must be done to thin the stand, and in doing this the worst of the young crabgrass is removed. The introduction of diversified farming in the South in which cowpeas, soybeans, or other crops that smother the weeds are grown, might, in addition to other benefits, reduce the stand of crabgrass, thereby reducing the

amount of hand work and as a consequence materially lowering the cost of production in this hard-pressed industry.

CROPPING SYSTEMS AND EROSION CONTROL

Susceptibility to erosion is an important factor in determining the kind and sequence of crops that should be grown on any particular piece of land. Erosion may result from action of either wind or water. That by wind is seldom serious except in dry-land areas such as the Great Plains. Erosion by water may occur anywhere that water moves over the land and is greatest and most damaging in areas of high rainfall and steep slopes.

The amount of erosion by water is influenced by the texture, structure, and organic-matter content of the soil. It may be modified by methods used in handling the soil and by the cropping practices employed. On lands subject to excessive erosion on account either of their slope or the character of their soil, cultivated crops such as corn, cotton, and tobacco subject the soil to destructive hazards. For example, on deep and fertile lands adapted to corn, this crop may have a prominent place in the rotation where the slope is slight. As the slope increases, corn should give way more and more to the small grains and sod crops and may finally, on steep slopes, need to be replaced entirely by protective crops or even by trees.

The same principles apply to other crops that are grown in rows and that are cultivated during their early growing season. This period is generally one of high rainfall, and the cultivation is chiefly for the purpose of destroying weeds and grass that compete with the crop, but which would protect the soil from erosion if left to grow. The cultivation itself fines the soil and puts it in condition to be easily washed away. Corn and the cultivated crops generally are soil destroyers, unless they are kept in their places by proper rotation.

A study made at the Missouri Agricultural Experiment Station (261) gave the results shown in table 2, which show strikingly how a good crop rotation reduces soil losses.

Table 2.—Average of 14 years' measurements of run-off and erosion at the Missouri Agricultural Experiment Station

[Soil type—Shelby loam; length of slope, 90¾ feet; degree of slope, 3.68 percent]

Cropping system or cultural treatment	Average annual erosion per acre	Run-off of rainfall	Cropping system or cultural treatment	Average annual erosion per acre	Run-off of rainfall
	<i>Tons</i>	<i>Percentage</i>		<i>Tons</i>	<i>Percentage</i>
Bare, cultivated, no crop.....	41.0	30	Rotation—corn, wheat, clover.....	2.7	14
Continuous corn.....	19.7	29	Continuous bluegrass.....	.3	12
Continuous wheat.....	10.1	23			

The prevention of loss of water by run-off, as shown in these experiments, is of especial significance for areas of limited rainfall or those subject to occasional drought. Where rotation was practiced the loss of water was less than half the amount lost from bare land and from land in continuous corn, about two-thirds that from land in continuous wheat, and only one-sixth more than from bluegrass sod. This

emphasizes the benefit of a suitable crop rotation in promoting greater efficiency in water conservation as well as in improving the soil.

With devices for controlling erosion, such as terracing, contour farming, and strip cropping, the question of crop rotation will require specific consideration in order to fit the cropping system into the plans adopted and the devices used. Rotations themselves may or may not need to be changed from those already practiced, but certain modifications often will be necessary. In strip cropping, especially, the kind and sequence of crops to be grown on the narrow strips established on sloping land will require careful planning, so that thick-growing crops, such as clover and wheat, will alternate with cultivated crops in successive strips up and down the slope. With strips following the contour, some irregular areas may need to be kept in permanent grass in order to avoid point rows. It will be difficult to utilize these grassed areas for pasture on account of the fencing involved. This will also be true to a greater or lesser extent for the entire stripped area. Considerable trying out of crops and methods will be required before proper rotations for strip cropping are fully worked out.

In dry-land areas where soil blowing must always be guarded against, strip cropping is being increasingly utilized as a protective device. In its simplest form and where most used in the northern United States and in the prairie Provinces of Canada, strips of grain are alternated with strips of summer fallow or corn. The following year the position of the crops is reversed. The grain stubble protects one strip while the other is in fallow, and the fallow strip is so narrow that blowing does not gain much headway. Very little is known regarding the adaptation of this method to other parts of the dry-land area. Growing corn or sorghums in strips alternating with wheat in other areas may favor injury by insect pests such as chinch bugs and grasshoppers, which migrate from one crop to another.

ROTATIONS USED IN THE UNITED STATES

There are no specific data on rotations practiced in this country as a whole. Many of the rotations practiced on individual farms, and rotations common in general areas, however, are known. It is certain that the combinations of crops into rotation systems are numerous and for the whole country very diverse.

In spite of the many different rotations practiced and the fact that no one rotation can be considered as typical, certain crops and systems of cropping tend to predominate in different sections of the country. Each principal type of farming region in the United States has one leading crop around which rotations and livestock production (if any livestock-production system can be used to advantage) are built up.

Some of the principal regions and the rotations practiced in them will be considered here, including the Corn Belt, the Cotton Belt, the dairy region, the wheat region, the dry-land area, and the irrigated sections.

Crop Rotation in the Corn Belt

A desirable rotation is one having the greatest net value over a period of years. Corn is the most valuable crop grown on practically all the farms in the Corn Belt. Therefore, the rotation of crops should be centered around corn. As much corn should be included in the rotation as is consistent with the maintenance of high acre yield and soil fertility and with the effective utilization of labor and equipment.

The particular rotation that should be chosen on an individual farm will depend on which one of many influences is a limiting factor in a given situation. The recommended proportion of corn in the rotation is usually determined by the

fertility of the soil, although the seasonal labor peaks at planting or harvest time may sometimes be more important factors. Corn and oats fit together almost perfectly from the standpoint of seasonal labor requirements, but oats usually have a much lower value per acre than corn. Soybeans compete with corn for labor and power but have a higher acre value than oats. The increased use of tractors for power has leveled off somewhat the spring labor peak that would have been caused by increasing the acreage of soybeans.

The value per acre of a specific crop must very often receive only secondary consideration in planning a rotation of crops. The oat crop may be less valuable per acre than any other crop grown, but it is usually necessary as a nurse crop for legume sod crops, which tend to maintain the yield of corn. Even the legume sod in the rotation is often justified more by its influence in maintaining corn yields than by its direct value for hay or pasture.

Sometimes cropping practices must be changed to make possible the effective use of a given rotation. Where clover seedings have become less certain year by year, it may be advisable to apply ground limestone or phosphate before increasing the acreage of clover and timothy which would otherwise consist largely of timothy. The use of a hybrid seed corn that is known to produce stalks less susceptible to breaking over may remove the principal difficulty in seeding winter wheat in the standing corn and thus make possible a corn-wheat-clover rotation.

There are ample statistics relating to the proportion of crops grown in various parts of the Corn Belt, but there is only fragmentary evidence concerning the way in which crops are rotated on individual farms. In a 3-year study made in central Indiana, the prevalence of rotations used was approximately as follows (71):

Rotation	Percent	Rotation	Percent
Corn, wheat, clover.....	30	Corn, soybeans, wheat, clover.....	9
Corn, oats, clover.....	27	Corn, corn, soybeans, wheat, clover.....	4
Corn, corn, oats, clover.....	14	Mixed rotations.....	3
Corn, corn, wheat, clover.....	4		
Corn, corn, oats, wheat, clover.....	2		
Corn, oats, wheat, clover.....	7	Total.....	100

Classified by percentage of corn in rotation, the following distribution is obtained:

Corn in rotation (percent)	Land (percent)
50	18
40	6
33	57
25	16
Total or average.....	37 100

These rotations represent the plans rather than the accomplishments on the farms studied. This sample of 100 farms represented farms that were more efficient than the average in central Indiana. With rotations being used in the proportion indicated, the average proportion of crops in rotation would be as shown in table 3, in which these percentages are compared with the actual proportion of crops grown on 362 farms in central Indiana in 1 of the 3 years.

Table 3.—Percentage of rotated land on 100 farms in central Indiana as calculated from frequency of planned rotations and as recorded in farm records at end of 1930

Crop	As calculated from frequency of planned rotations	As recorded in farm records at end of 1930	Crop	As calculated from frequency of planned rotations	As recorded in farm records at end of 1930
	Percent	Percent		Percent	Percent
Corn.....	35	37	Clover and alfalfa.....	30	19
Oats.....	15	16	Miscellaneous crops.....		4
Wheat.....	17	17			
Soybeans.....	3	7	Total.....	100	100

The principal difference between the planned rotations and the achieved results was in the proportion of the rotated acreage in legume sod. On the farms studied from 1929 to 1931, 92 percent of the wheat and 78 percent of the oat acreage were sown with clover and alfalfa. These figures suggest a 3-year average clover failure of 33 percent. It is also indicated that most of the land on which clover seedlings failed was planted to corn and soybeans with a slight increase in oats and miscellaneous crops.

In the central Indiana area, soil adaptation and method of harvesting corn are the principal factors determining whether wheat or oats are used in a 3-year rotation. The use of a corn-wheat-clover rotation is more nearly general in a locality where the soil is better adapted to wheat than to oats and where the corn is usually cut and shocked. On another large group of farms, the wheat is ordinarily sown in the standing corn. In the latter case a part of the cornland is usually seeded to oats.

For several reasons, more than one rotation is often used on the same farm. Variation in the type of soil or slope of the land may dictate a different percentage of corn on one part of the farm than on another part. On some farms where the crop is hogged off, one field is planted to corn continuously for a much longer period than is called for by the regular rotation. The desire for a field of alfalfa close to the buildings may alter the rotation of crops for a few fields. Convenience in the pasturing of livestock is another reason for having a minor rotation of small fields near to the buildings, even though it sometimes means an additional expenditure for fencing.

On the fertile soil of north-central Iowa, corn is grown on a much larger proportion of the rotated land than in the central Indiana area for which sample crop rotations have been given. In a 4-year study made in Webster County, Iowa, the following crop sequences are listed (170):

Crop sequence	Percent of acres
Corn, oats.....	46
Corn, corn, corn, oats.....	24
Corn, corn, oats, clover.....	5
Corn, oats, clover.....	4
Corn, oats, pasture, pasture.....	3
Alfalfa 2 or more years.....	2
Other sequences.....	16
Total.....	100

On about one-half of the rotated land 50 percent was in corn each year, and on an additional one-fourth of it 75 percent was in corn each year. The proportion of hay and pasture crops is much too low in this area to maintain the yield per acre of corn even on the fertile Webster loam common to the area.

In some areas in the southern part of the Corn Belt, the percentage of the rotated land in corn seems very low, but the sequence of crops indicates an exhaustive cropping system. A typical crop sequence in parts of northern Missouri includes corn for 3 years, small grain 1 or 2 years, and seeding to a mixture heavy with timothy, which remains 5 or 6 years. At about the time that bluegrass should be getting well established it is usually broken up again for corn.

The cropping system usually affects the number and kind of livestock more than it is affected by them, but there are some instances where livestock management influences the kind and proportion of crops grown. A dairy herd may require a larger quantity of high-quality roughage than a beef herd. If the crops that are grown are fed to livestock and the crop residues and manure are spread on the cropland, a higher percentage of corn in the rotation may be justified than if the crops are sold off the farm.

The availability of certain kinds of farm equipment may also have some influence on the kinds of crops grown. The big expansion in acreage of soybeans for grain came only after a large number of combined harvester-threshers were available. Some farmers have rented additional cornland because an efficient two-row corn picker enabled them to meet the seasonal peak of labor requirements at harvest time. The more flexible daily capacity of tractors has also been very instrumental in reducing the number of days to perform the peak power load and has made possible certain combinations of crops that could not have been handled economically with horse power.

Crop Rotations for the Cotton Belt

For the purposes of maintaining soil fertility, preventing erosion, and controlling weeds, insect pests, and plant diseases, the need for effective crop rotations probably is greater in the Cotton Belt than in any other part of the country. However, definite crop rotations or crop sequences are much less common on cotton farms than on farms on which a more general type of farming is followed. Many cotton farmers follow a more or less definite cropping system, but no data are available to indicate the usual sequence in which the various crops are grown or to what extent a practice prevails in any particular section.

There are several reasons why cotton farmers generally do not follow a more definite system of crop rotation. Cotton normally occupies a larger percentage of the cropland than any other crop, frequently more than half of the entire harvested crop acreage. This is not only because cotton is the most valuable crop grown, but also because the small number of livestock kept on most cotton farms makes the acreage required for the production of feed crops relatively small. Because of these conditions the cropping system on a typical cotton farm on which the soil is relatively uniform as to productivity and crop adaptation usually consists of 1 year in corn or an annual hay crop, or both, and from 2 to 4 years in cotton. Under a cropping system of this kind the corn may or may not be interplanted with cowpeas, soybeans, or velvetbeans; if part of the land is in winter grain this may be followed with cowpeas, soybeans, or lespedeza.

Another difficulty in following definite crop rotations in the Cotton Belt is the fact that on the larger plantations most of the cotton is grown by sharecroppers who have little use for feed crops, and who prefer to grow cotton continuously. Under these conditions there seldom is any attempt made to follow definite rotations, and cotton usually is grown year after year on the same land.

In many parts of the Cotton Belt—particularly in the upland, hilly section—numerous small, irregular fields and a wide variation in the productivity and adaptability of the soil to the various crops grown make conditions unfavorable to the adoption of a definite rotation or sequence of crops that may be applied to the entire farm. On many farms part of the land may be good cotton land but poor cornland; other parts of the farm are good cornland but not well suited for cotton. An attempt to set up and carry out a definite crop rotation for the entire farm under these conditions will necessitate planting cotton some years on land that is low in productivity or otherwise unsuited to its production. Where such conditions prevail it is not an unusual practice to adopt one cropping system for the cotton land and another for the cornland. Cotton well fertilized will be grown continuously on the cotton land, and corn and other miscellaneous crops on the cornland.

As a means of reducing fertilizer expenses and increasing crop yields, considerable interest has been shown in the growing of winter legumes, vetch, Austrian Winter peas, crimson clover, and bur clover, and the acreage planted to these crops has increased tremendously in the Cotton Belt in the past few years. Data from 386 cotton farms on which 4,145 acres of corn and 1,877 acres of cotton were grown after winter legumes showed an average acre increase of 14.1 bushels of corn and 100 pounds of cotton lint where these crops followed a crop of winter legumes plowed under for green manure (233). This amounted to an increase of 70 percent in the yield of corn and 35 percent in the yield of cotton. Of the total acreage of winter legumes grown on these 386 farms approximately 58 percent was vetch, 38 percent Austrian Winter peas, and 4 percent crimson clover and bur clover.

While these results were highly satisfactory in the increase of crop yields, only about 6 percent of the cropland on these 386 farms was in winter legumes. This was due in part to the expense of winter-legume seed and in part to the difficulty sometimes encountered in obtaining a stand because of dry weather at seeding time. The most usual practice in seeding winter legumes is to sow the seed in the cotton middles. This is because cotton is cultivated later than corn or other row crops, and the cotton middles usually are relatively clean and free from weeds, whereas corn middles frequently are planted in cowpeas, soybeans, or velvetbeans.

Since cotton is the principal crop, both as regards acreage and value, it is obvious that crop rotations for the Cotton Belt should be centered around this crop. Moreover, the rotation adopted for any particular situation will depend to a large extent on the proportion of cropland that is to be devoted to cotton.

In areas in which approximately one-third of the cropland is in cotton, and where the land is equally well adapted to the production of cotton and corn, a desirable rotation would be:

First year, cotton.

Second year, summer legumes (cowpeas or soybeans) for hay or seed, followed by winter legumes.

Third year, corn, interplanted with cowpeas, soybeans, or velvetbeans.

A variation of this rotation that would be suitable for some sections would be to follow the cotton with a winter grain, which in turn would be followed with a summer legume or lespedeza.

Where it is desirable to have approximately one-half the land in cotton the following rotation is suggested:

First year, cotton, followed in part by a winter legume.

Second year, cotton.

Third year, summer legumes for hay or seed followed by winter legumes.

Fourth year, corn, interplanted with summer legumes.

In this, as in the 3-year rotation, the second-year cotton may be followed wholly or in part by winter grain, etc.

Winter legumes as a green manure may be effectively worked into the cropping system on farms on which the proportion of land adapted to cotton is limited to approximately the required acreage for this crop. Here a limited acreage of winter legumes may be planted on part of the cotton land each year, the plantings being shifted so that the winter legumes will be gradually rotated over the entire cotton acreage. In this way a portion of the cotton will follow a winter-legume crop each year. On the remainder of the farm a rotation of corn interplanted with summer legumes may be grown each year, or the land may be divided into two approximately equal areas and corn alternated with a small-grain crop followed by a summer-hay crop, according to the requirements of the farm.

A rotation of crops is essential in some areas in order to control or hold in check certain cotton diseases. Root rot is the most destructive cotton disease in the United States, and is particularly destructive in the heavy, black, waxy soils of Texas. Root rot also affects practically all farm crops except corn, small grains, sorghums, and grass. It also affects many trees, shrubs, and weeds. Where this disease is prevalent the recommended rotation is cotton 1 year, and corn, small grain, grain sorghum, or a grass crop for 2 to 4 years.

Crop Rotations in the Dairy Region

North of the Corn Belt and east of the wheat region, where the summers are too cool and the growing season too short for maturing corn consistently and where no large tracts of easily tilled, fertile prairie land exist for wheat production, there is a region where hay and pasture predominate. This region includes most of Minnesota, Wisconsin, Michigan, New York, northern Pennsylvania and New Jersey, and the New England States. During the early settlement of this region and up to about 1870 in the Northeast, wheat and corn for grain were grown in considerable amounts. But with the rapid extension of farming in the prairie States, and the development of large and improved machinery, production of corn, wheat, and other small grains increased so rapidly that prices fell too low for the present dairy region to compete in the cash-grain markets. Consequently, adjustments in crops and accompanying adjustments in livestock were started in what is now the principal dairy region of the United States. Practically no wheat and only small quantities of oats and other feed grains are now grown in New England. New York grows slightly more feed grains and also has some wheat production in a limited area of the western part of the State. The Lakes States grow most of the feed grains used by the dairy and work stock on the farms, but they produce little grain for market.

Most of the dairy farms in the Lakes States have some land either too rough for crops or not cleared that furnishes considerable feed for 3 to 6 months when pastured. In this situation a 3-year rotation of corn—mostly for silage—oats, and clover is popular. These States are important potato producers, so that the substitution of some potatoes for corn as the intertilled crop is common. Usually a mixture of clover and timothy or alfalfa and timothy which may be kept 2 years for hay is sown with the spring grain. When permanent pastures are short, the second year of hay may be partly or wholly pastured. If the new seeding fails, the old sod may be kept over another year or an annual hay crop may be sown.

In some cases a field may be kept in alfalfa for 3 or 4 years and then be put in the regular rotation again.

In a representative area in northern Wisconsin a group of farms averaged the following acreages of crops per farm: Corn for silage, 11; corn for grain, 0.5; potatoes, 3; oats, 13; barley, 3.6; and hay, 19. Woods and permanent pasture amounted to 50 acres, and the total farm area to 104 acres. The ratio of cultivated crops to small grains and hay of 14.5, 16.6, and 19 acres, respectively, is due to the fact that a small proportion of the farmers keep their hay seeding down 2 years while most of them keep the hay seeding down only 1 year. It illustrates how a dairy farmer can expand milk production if milk prices increase relative to other products, which is just what has happened on most farms that have remained in dairying in the eastern part of the dairy region.

According to farm-management surveys (449, 450) covering the calendar year 1930, Hunterdon and Sussex Counties in northern New Jersey, although less than 50 miles apart, showed a marked contrast between general farming and highly specialized dairy farming. One hundred and seventy-six farms in Hunterdon County had an average of 69 acres of crops approximately in the proportion of a rotation of corn, oats, wheat, hay, and hay, and also had 29.5 acres of pasture. Ninety-eight Sussex County farms had an average of 64 acres of crops approximately in the proportions of a rotation of corn, oats, hay, hay, and hay and had 91 acres of pasture. By utilizing the tillable land in the dairy area for growing roughage for the cows and the more rolling land for pasture, and supplementing these with liberal rations of purchased concentrates, the size of the dairy business on a given farm can be greatly increased.

In many parts of New York and most of New England the percentage of cropland in hay is even higher than in Sussex County, N. J. In Berkshire County, Mass., hay was the crop harvested on 84 percent of the cropland in 1929. In Grafton County, N. H., hay was on 89 percent of the cropland harvested, corn and oats on 3 percent each, and potatoes on 2 percent. Many hayfields are not reseeded for 10 to 20 years. Under these conditions, hay yields usually decline to a low level.

Crop Rotations in the Wheat Regions

The areas of heaviest concentration of wheat in the United States occur in three regions. In each, a type of wheat adapted to the natural conditions of the area is grown. Definite crop rotations are not a part of farming practice in the important wheat-producing areas. Wheat may not be grown continuously on the same fields, but even those farmers who maintain a higher-than-average proportion of their land in crops other than wheat do not usually follow one crop with another specific crop in orderly sequence. The general disregard for formal crop-rotating systems is not because fertility maintenance or weed control have not become serious, for in certain sections both are important. It is due to climatic hazards that make the continuous-cropping system uncertain; to lack of an easily established legume; and, most important, to the lack of a crop that can compete successfully with wheat in yielding returns for the use of land, labor, and capital.

In general-farming areas extending from eastern Kansas through Missouri, Illinois, Indiana, and Ohio to Pennsylvania, Maryland, and Virginia, wheat has an important, although not a predominant, place in the cropping system. It may occupy no more than one-fifth or even a smaller proportion of the rotated land in a sequence of corn, small grain, and hay or grass. Whatever the sequence of crops, wheat may be grown to obtain a combination with grass seedings or for straw as well as for grain.

The hard winter wheat producing area comprises the western two-thirds of Kansas and extends south into western Oklahoma and northern Texas, west into Colorado, and north into Nebraska. The portions of the area devoted to wheat production may be characterized in general by a level or undulating relief; heavy, fertile soil; and by precipitation decreasing from 25 inches in the eastern portions to 15 or 18 inches in the western portions. Cropping systems vary with precipitation and to some extent with soil type. Crop acreages on a number of wheat farms in Clay and Saline Counties, Kans., as reported by farmers in 1933, when expressed as a percentage of total cropland showed that 62 percent of the 263 crop acres per farm was seeded to winter wheat. Another 6 percent was in oats or barley. Thus, two-thirds of the cropland was in small grains. Corn occupied

18 percent of the land and sorghums for grain or forage 4 percent, which placed a little more than one-fifth of the cropland in intertilled crops. Hay, mostly alfalfa, was reported on 6 percent of the cropland. Farther west, wheat is even more the predominating crop. In the area represented by Russell, Rush, Stafford, and Mitchell Counties, approximately 80 percent of the crop acreage was planted to wheat. Other small grains are relatively unimportant, but in the western portions of the area corn occupied 12 percent and sorghums 8 percent of the land. There was very little hay. In the portions adjacent to the eastern division of the area less corn and more alfalfa were grown.

In the western part of the winter wheat area centering around Ford and Haskell Counties, Kans., and extending to the west, wheat on the grain farms was seeded on 87 percent of the cropland. In the northern portions of the winter wheat region, corn and the small feed grains occupy a larger share of the cropland, and greater opportunities for rotating crops are presented. On the eastern border of the northern limits of the winter wheat area, corn utilizes a larger proportion of the cropland than wheat. Corn is likely to be followed by corn or spring grains and wheat to be followed by spring feed grains or wheat. Roughly the system could approximate a rotation of corn 2 years, oats or barley 1 year, and wheat 2 years with some likelihood that sweetclover or some other hay crop would be included.

Cropping systems common in the spring wheat area, centered in North Dakota and extending into Minnesota on the east, South Dakota on the south, and Montana on the west, are determined by the adaptation of the area to spring-seeded small grain, the limiting influence of temperature and moisture on corn production, difficulties of controlling weed infestations, and to some extent by the effects of plant diseases. In this area as in others in which climate, particularly precipitation, exhibits a high degree of variability, orderly rotations or sequences of crops are not always practicable. Generally speaking, wheat or other small grains occupy the major portion of the cropland. In the southern portions of the area corn is included in the rotation. Potatoes are included on some of the lighter soils in the eastern sections; and sweetclover, used for hay, pasture, or soil improvement, occupies a portion of the land in the eastern Dakotas.

In an area typical of the Red River Valley, one-third of the 440 acres of cropland per farm was either in hard red spring or durum wheat and 27 percent was in other small grains or flax, crops which occupy the same position in the cropping system. Only 4 percent of the land was in a cultivated crop, corn or potatoes, 15 percent was in hay or sweetclover pasture, and 15 percent was either fallow or in crops plowed under for soil improvement. Records on a number of farms included in an earlier study indicated that farmers on lighter soils were approximating a rotation of (1) small grain, 2 years; (2) sweetclover for hay, pasture, or green manure; and (3) corn or potatoes. Other farmers, however, were attempting nothing more than a continuation of small-grain crops with the sequence broken by occasional crops of sweetclover or perhaps row crops. Where the fields were badly weed-infested, farmers might resort to summer fallow to clean their fields.

In the southern portion of the spring wheat area where corn has a definite part in the cropping system, corn occupied about 20 percent, wheat about 40 percent, and small feed grains about 30 percent of the crop area totaling 380 acres. Some alfalfa and a small amount of sweetclover were grown on an acreage equivalent in the eastern part of the area to 6 percent of the cropland. In this area of north-eastern South Dakota, 60 percent of the wheat followed spring grains, 10 percent was on fallow, and 30 percent on row-crop land. This distribution of crops would permit a rotation of small grains 4 years and row crops 1 year with a portion of the acreage in legumes.

The cropping systems in the western portions of the spring wheat area are discussed under Dry-Land Rotations.

In the Pacific Northwest—the wheat areas in eastern Oregon, in Washington, and in Idaho—dry-land wheat production has been carried on for nearly 50 years. Beginning with a practice of growing a crop each year, as a means of controlling weeds and to increase the dependability of yields, farmers shifted from continuous wheat, first to a system of fallow every third year, and finally to a system in which the greater portion of the acreage of wheat in areas of 15 to 18 inches of precipitation is now alternated with fallow. In the Palouse section in 1933, 78 percent of the winter wheat and 58 percent of the spring wheat were seeded on fallow, and 23 percent of the winter wheat and 34 percent of the spring wheat

followed cultivated peas. A small acreage of small feed grains was usually seeded after small grains on stubble land.

The typical rotation of the area is more closely followed in the section near Walla Walla, Wash., and in Sherman County, Oreg. In both of these areas and in the Big Bend area of Washington practically all of the cropland is included in a wheat, summer-fallow rotation. The lack of any crop that closely competes with wheat in returns and the practical success of the system has given it wide adoption.

Dry-Land Rotations

There are some points in common between practically all portions of the Great Plains and the intermountain dry-land areas that help determine rotation practices. Wheat, either winter or spring, is the preeminent cash crop, except for a few sections where the soils are unsuitable for wheat production and limited areas where a cash crop of greater value is adapted. The proportion of wheat in the farmer's program, however, varies from almost the sole crop to a place subordinate to feed crops. Sod crops, an integral part of rotation practice in humid and subhumid areas, are unsuitable for short rotations, because of the dry condition in which they leave the soil, and their value in deferred rotations is still to be determined. Manures, both green and stable, are ineffective in increasing grain yields, although they increase the yields of straw and stover. These latter facts explain why dry-land rotations do not conform to some of the general principles considered essential in crop rotations elsewhere.

Summer fallow enters into dry-farming rotations in most sections. The term "summer fallow" as applied in dry-land areas means keeping the land free from weeds or competing crop growth during one crop season in order to store moisture for the next. This differs from the use of the word in other sections where land that stands idle or that grows a crop of weeds part of the year is often termed "fallow."

The place of fallow in rotations depends upon the extent to which it increases crop yields, and on the competition of other crops, particularly cultivated crops. In general, the drier the section and the lower the adaptation of cultivated crops, the more important may be the use of fallow to the agriculture of the section. The use of summer fallow in dry-land rotations is considered in more detail elsewhere in the Yearbook under Special Dry-Farming Problems.

Wind erosion is a factor that must be considered in dry-land rotations. Certain crops, such as annual legumes, leave the soil in condition to blow readily and often are best grown in strips with crops that leave resistant residues. In general, however, the handling of the land and of the crop residues upon it within a rotation are the principal means of controlling wind erosion. Susceptibility to erosion is often the deciding factor in determining the rotation and cropping practices.

Rotation practices involving wheat as a principal crop have been considered under the discussion of crop rotations in the wheat regions. The addition of another crop with an acre value comparable to wheat may profoundly alter farm practice in a section. In portions of Washington, Oregon, and Idaho peas grown in cultivated rows have displaced some of the fallow. The yields of wheat following peas are lower than those following summer fallow, but at prevailing prices the value of the pea crop has been greater than the reduction in value of the following wheat crop.

In the important grain sorghum sections in the southern Great Plains, there is difficulty in suggesting an adequate rotation. Much of the land is too sandy for successful wheat production, and the presence of a high row-crop stubble over winter may be necessary to prevent wind erosion. Growing strips of annual legumes between strips of sorghum in lieu of a rotation has been practiced. The purpose, however, generally has been to avoid destructive soil blowing on legume land rather than to make a conscious effort to rotate crops. On land where winter wheat and sorghums can both be grown and where summer fallowing materially increases the yields of wheat, a rotation of summer fallow, wheat, and grain sorghums may be adapted. By fallowing the sorghum stubble, the severe reduction in wheat yield that is experienced when winter wheat follows sorghum is avoided. A 2-year rotation of sorghum and wheat is not advisable. More sorghum and wheat can be produced by growing each continuously on the same land than by alternating them.

Continuous cropping, either to cultivated crops or to small grains, has not been so bad a practice in the dry-land area as in wetter or irrigated sections.

Manures in dry-land areas must be considered in the light of their potential value in helping maintain the organic-matter content of the soil rather than as a fertility element from which worth-while yield increases may immediately be expected. This value remains to be determined. Cumulative increase of grain yields from rotations containing manures have seldom been evident, even on rotations that have a history of as much as 25 years. Soil studies, however, show that less reduction in organic matter has taken place on rotations receiving manure. Manures have been very useful in improving the physical condition of some heavy soils.

The lack of grass crops or alfalfa in the rotations given does not mean that these crops have no place in dry-land farming. Present knowledge of these crops indicates that they should be planted in favored locations and allowed to stand while production remains good.

Crops other than those mentioned are important in parts of the region. Cotton largely displaces sorghums in the southern part of the Great Plains. Potatoes are an important cash crop in parts of western Nebraska. Dry beans are a cash crop in several States, and dry or canning peas are grown in portions of the inter-mountain region. Where these cash crops can be successfully grown they assume an important place in the rotations.

In general, it may be stated that the yields of crops and their immediate effect upon each other are the matters of immediate concern in arranging dry-land rotations. Fertility up to the present time has been of secondary importance. The soil was highly productive in its virgin state, and the limitations on production set by the low rainfall characteristic of the region have prevented lack of fertility from assuming an important place as yet. Only continued studies can determine the level of fertility at which it may be the controlling factor in determining the quantity of crop produced.

Crop Rotations in Irrigation Agriculture

The virgin productivity of extensive irrigated areas located in the arid and semiarid West is well recognized, and long-continued investigations have clearly shown that where a satisfactory farm-management program has been in effect, crop yields not only have been sustained, but during a period of over a quarter of a century they have been substantially increased.

At the Huntley (Mont.) Field Station from six untreated rotations for the first 3 years of a long-time experiment, 1912-14, sugar beets returned a mean yield of 10.2 tons per acre, and from potatoes there was a mean yield of 209 bushels per acre from five untreated rotations. These yields are a fair measure of the original productiveness of the soil. After 20 years of continuous and intensive cropping, the mean yield of sugar beets from four constructive rotations including either farm manure or pasturing was 13.4 tons per acre, and from potatoes in four similar rotations the mean yield was 242 bushels per acre. These differences represent an increase of 31 percent for sugar beets and 16 percent for potatoes.

Similar comparisons are available at the Scotts Bluff (Nebr.) Field Station. In its virgin state the land representative of the North Platte reclamation project proved to be somewhat more productive. From six untreated rotations from 1912 to 1914 the mean yield of sugar beets was 16 tons per acre, and of potatoes from five comparable rotations there was harvested a mean yield of 219 bushels per acre. After a lapse of 20 years, from four of the better rotations including sugar beets there was harvested a mean yield of 17.9 tons of beets, and from five rotations including potatoes the mean yield was 252 bushels per acre. These differences represent an increase of 12 percent for sugar beets and 15 percent for potatoes.

There is ample evidence elsewhere throughout the West to demonstrate that where good farming practices are in effect crop yields of a high order are being harvested on such irrigated areas as those lying along the North Platte, South Platte, and Yellowstone Rivers; the Columbia River Basin; the lower Colorado River; and the extensive areas supplied from the waters of the Salt River and Rio Grande. This condition exists even in view of the fact that irrigation farming has been conducted for nearly half a century in a number of these localities.

Extensive acreages, either completely abandoned or unprofitably operated on many irrigation enterprises scattered throughout the West, are impressive demonstrations of the unjustifiable optimism as to the productive future of such areas without a suitable program of management. It has been assumed too generally

that the problems involved in connection with maintaining crop yields were not complex and could be readily solved by the farmers themselves. These all too extensive areas with impaired productivity clearly demonstrate that this is not a fact.

Under proper management and where the soil, water, and climatic conditions are not unfavorable the acre yields of the various crops produced under irrigation should be superior to those harvested where such conditions do not exist. But in eliminating the hazards of drought, which has long been recognized as an important limiting factor in securing large crop yields, and in taking advantage of an assured water supply, farmers assume other responsibilities in connection with their operations, which if not adequately met still endanger their success. A substantial proportion of the costs of crop production under irrigation is in the form of fixed charges, which must be met regardless of the size of the crop harvested or even if there is a total crop failure. Thus, while the possibilities of obtaining larger returns per acre are greater where the hazards of drought have been eliminated, the financial risks are correspondingly increased if the productivity of the soil is not so maintained that superior yields are assured.

Farmers producing crops under such conditions and confronted with increased operating costs are forced into a more intensive system of farming, as mediocre yields will not cover production costs and fixed charges. Such measures as summer fallowing, often resorted to advantageously in adjoining dry-land areas, are not practical. Because of the intensive cropping of the lands, which is essential to success, the productivity of the lands becomes more rapidly depleted unless a soil-improving farm program is practiced, and the ultimate consequences are more serious to the operators than is the case where the required standard of production is materially less. It is evident, therefore, that a successful agriculture under irrigated conditions is predicated upon the adoption of such a program of farm management that crop yields may be large enough to insure returns in excess of the fixed charges and costs incident to their production. To attain this objective a well-planned crop-rotation program is now known to be essential.

The basic purpose of crop-rotation investigations is to provide authentic information as to the crops together with the sequences and the soil amendments necessary to develop conditions favorable for normal, vigorous plant growth. This was the objective when an extensive series of irrigated rotations was inaugurated at the Scotts Bluff, Nebr., the Belle Fourche, S. Dak., and the Huntley, Mont., Field Stations in 1912.

It has been found that the rotation of crops alone is not an insurance against soil exhaustion, even when alfalfa or a similar leguminous crop is included in the cropping program, and that good rotations alone will not maintain crop production indefinitely without supplementary amendments, except in unusual circumstances.

It has been only within the past 5 years that data have been available indicating that yields of sugar beets and possibly certain other crops will eventually decline in rotations with alfalfa to such a degree that the yields are but little better than when grown for a like number of years in simple rotations not including a leguminous crop.

It has taken many years of careful experimentation to provide reliable data as to the merits of varying applications of farm manure as compared with alfalfa and certain other leguminous crops grown in rotations with staple farm crops. Where these crops are grown throughout the irrigated West, farm manure has been found to be the most effective agency in maintaining and improving the productivity of the land. However, this soil amendment is rarely available in sufficient amounts to fulfill the needed requirements. In certain instances mineral fertilizers may be utilized to advantage, but their cost is an important item, particularly when the prices of farm products are depressed. Often, therefore, it is necessary for the farmer to provide other means of maintaining the productivity of the soil. In such instances a promising solution of the problem is the inclusion in the rotation of such leguminous crops as alfalfa or sweetclover, and pasturing one season during the cycle of the rotation. It has been found that by pasturing alfalfa or sweetclover production costs are reduced, the net returns per acre are greater than those obtained when the hay is marketed, and subsequent crop yields are stimulated to an extent often equaling such intensive treatments as the inclusion of alfalfa and applications of farm manure when combined in the same rotation.

Crop Yields Materially Influenced by Crop Sequences

It has been found that where three or more crops are grown in rotation the arrangement of the crop sequences often has an important effect on the yields of certain of the crops. Investigations have shown that where sugar beets are grown in a 3-year rotation with oats and potatoes, the yields of sugar beets are definitely depressed if oats are the preceding crop but are satisfactory following potatoes. On the other hand, potato yields have been satisfactorily maintained following oats. Thus if oats or similar cereals are included in the farm program which also includes potatoes and sugar beets—crops commonly grown on a number of the larger projects—the proper arrangement of the crop sequences is highly important. Leguminous crops such as alfalfa and sweetclover, which are so extensively included in the farm program for soil-improvement purposes, are commonly grown 2 or more years, after which the land is prepared for the more important revenue-producing crops. Cropping programs including sugar beets, potatoes and 2 or more years of alfalfa are characteristic of the practices found on many irrigation projects. Ordinarily the yields of sugar beets immediately following alfalfa are low, but relatively satisfactory yields are to be expected from potatoes immediately following alfalfa. Sugar beets following potatoes in such a rotation have shown increases of more than 70 percent in excess of the alfalfa, sugar beet, and potato combination, and at the same time the yields of potatoes following alfalfa have compared favorably with rotations in which the crop is one or more years removed from alfalfa. Often such results as these have confused farmers and at times have led them to question the benefits to be derived from including alfalfa in the planting program. It is fortunate that now more precise information is available as to the probable effect on crop yields of various crop sequences.